

GM Crops & Food > Biotechnology in Agriculture and the Food Chain Volume 8, 2017 - Issue 3

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Farm income and production impacts of using GM crop technology 1996–2015

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Pages 156-193 | Received 10 Feb 2017, Accepted 04 Apr 2017, Published online: 19 Jun 2017

Cite this article <https://doi.org/10.1080/21645698.2017.1317919>

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having, for example, added 180 million tonnes and 358 million tonnes respectively, to the global production of soybeans and maize since the introduction of the technology in the mid 1990s.

KEYWORDS: [cost](#) [genetically modified crops](#) [income](#) [production](#) [yield](#)

INTRODUCTION

2015 represents the twentieth year of widespread cultivation of crops containing genetically modified (GM) traits, with the global planted area of GM-traited crops at about 172 million hectares.

During this 20-year period, there have been many papers assessing the farm level 'economic' and farm income impacts associated with the adoption of this technology. The authors of this paper have, since 2005, engaged in an annual exercise to aggregate and update the sum of these various studies, and where possible and appropriate, to supplement this with new analysis. The aim of this has been to provide an up to date and as accurate as possible assessment of some of the key farm level 'economic' impacts associated with the global adoption of crops containing GM traits. It is also

hoped that this work will help to inform the impact of this technology in countries where it is not yet widely used.

This study is part of a series of papers published in the *Journal of Agricultural Economics* since the introduction of GM crops for 2015.

Previous studies have included: [Brookes and Barfoot, 2012](#), [Brookes and Barfoot, 2013](#), [Brookes and Barfoot, 2014](#), [Brookes and Barfoot, 2015](#), [Brookes and Barfoot, 2016](#) (Brookes and Barfoot, 2016).

The *Journal of Agricultural Economics* is a peer-reviewed journal published by Blackwell Publishing. The journal covers a wide range of topics related to agriculture, including the impact of GM crops.

The journal is published quarterly, with issues in March, June, September and December.

The journal is available online at [http://www.blackwell-synergy.com/doi/full/10.1111/j.1474-7480.2015.00000.x](#).

The journal is also available in print form, with a subscription price of £120 per volume (2015).

The journal is published by Blackwell Publishing, 108 Cowley Road, Oxford OX4 1JF, UK.

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that some of the data presented



in previous analysis because the current paper takes into account the availability of new data and analysis (including revisions to data for earlier years).

To save readers of this paper the chore of consulting the past papers for details of the methodology and arguments, these are included in full in this updated paper.

The analysis concentrates on gross farm income effects because these are a primary driver of adoption among farmers (both large commercial and small-scale subsistence). It also quantifies the (net) production impact of the technology. The authors recognize that an economic assessment could examine a broader range of potential impacts (eg, on labor usage, households, local communities and economies).

However, these are not included because undertaking such an exercise would add considerably to the length of the paper and an assessment of wider economic impacts would probably merit a separate assessment in its own right.

RESULTS AND DISCUSSION

HT Crops

The main impact of GM HT (herbicide tolerant) crops is that they allow the use of glyphosate herbicides, which are easier to apply and less expensive than other herbicides. Glyphosate is derived from a natural source and is more selective than conventional herbicides and is more effective against weeds. The cost of glyphosate is lower than that of other herbicides, and the cost of applying it is also lower. The use of glyphosate has increased in recent years.

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2009, the average cost associated with the use of GM HT technology globally increased significantly relative to earlier years because of the increase in the global price of glyphosate relative to changes in the price of other herbicides commonly used on conventional crops. This abated in 2010 with a decline in the price of glyphosate back to previous historic trend levels;

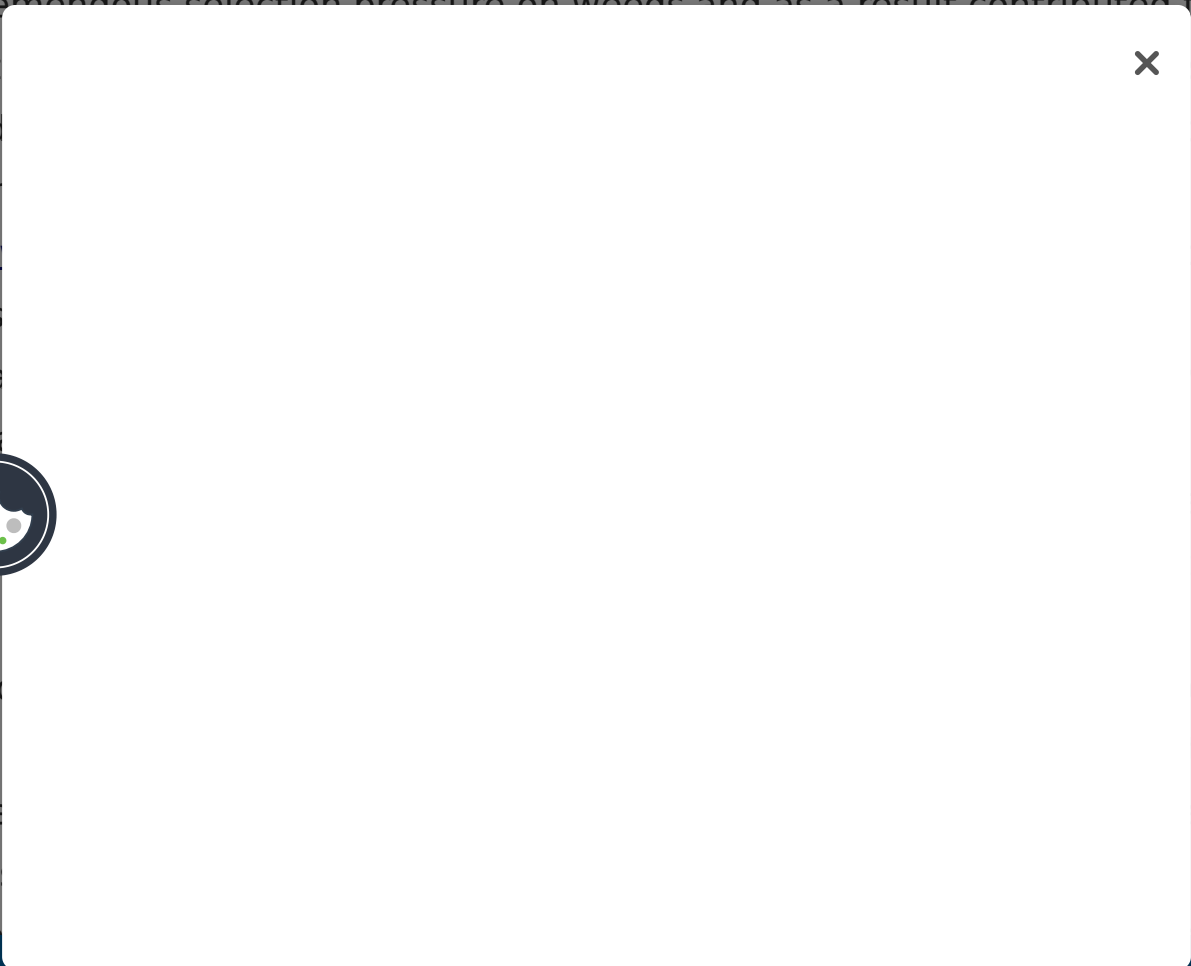
- The amount farmers pay for use of the technology varies by country. Pricing of technology (all forms of seed and crop protection technology, not just GM technology) varies according to the level of benefit that farmers are likely to derive from it. In addition, it is influenced by intellectual property rights (patent protection, plant breeders' rights and rules relating to use of farm-saved seed). In countries with weaker intellectual property rights, the cost of the technology tends to be lower than in countries where there are stronger rights. This is examined further in c) below;

- Where GM HT crops (tolerant to glyphosate) have been widely grown, some incidence of weed resistance to glyphosate has occurred and resistance has become a major concern in some regions. This has been attributed to how glyphosate was used; because of its broad-spectrum post-emergence activity, it was often used as the sole method of weed control. This approach to weed control put tremendous selection pressure on weeds and as a result contributed to the

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glyphosate have not been found. This change in weed management emphasis also reflects the broader agenda of developing strategies across all forms of cropping systems to minimise and slow down the potential for weeds developing resistance to existing technology solutions (Norsworthy et al., [2012](#)). At the macro level, these changes have influenced the mix, total amount, cost and overall profile of herbicides applied to GM HT crops. Relative to the conventional alternative, however, the economic impact of the GM HT crop use has continued to offer important advantages for most users. It should also be noted that many of the herbicides used in conventional production systems had significant resistance issues themselves in the mid 1990s. This was one of the reasons why glyphosate tolerant soybeans were rapidly adopted, as glyphosate provided good control of these weeds. If the GM HT technology was no longer delivering net economic benefits, it is likely that farmers around the world would have significantly reduced their adoption of this technology in favor of conventional alternatives. The fact that GM HT global crop adoption levels have not fallen in recent years suggests that farmers must be continuing to derive important economic benefits from using the technology.

These points are further illustrated in the analysis below.

GM HT Soybeans

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GM HT soybeans have also facilitated the adoption of no tillage production systems, shortening the production cycle. This advantage has enabled many farmers in South America to plant a crop of soybeans immediately after a wheat crop in the same growing season. This second crop, additional to traditional soybean production, has added considerably to farm incomes and to the volumes of soybean production in countries such as Argentina and Paraguay.

Overall, in 2015, GM HT technology in soybeans (excluding second generation 'Intacta' soybeans: see below) has boosted gross farm incomes by \$3.82 billion, and since 1996 has delivered \$50 billion of extra farm income. Of the total cumulative farm income gains from using GM HT soybeans, \$23.6 billion (47%) has been due to yield gains/second crop benefits and the balance, 53%, has been due to cost savings.

GM HT and IR (Intacta) Soybeans

This combination of GM herbicide tolerance (to glyphosate) and insect resistance in soybeans was first grown commercially in 2013, in South America. In the first 3 years, the technology was used on approximately 22.3 million hectares and contributed an additional \$2.4 billion to gross farm income of soybean farmers in Argentina, Brazil, Paraguay and Uruguay. The net benefit to farmers (gross income less herbicide expenditure on herbicide tolerant crops) was \$1.8 billion.

GM HT

The adoption of GM HT soybeans has been widespread, although yield gains have been modest. In the Philippines, GM HT soybeans were first grown in 2013.



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\$3.44 billion (31%) was due to yield gains and the rest derived from lower costs of production.

GM HT Cotton

The use of GM HT cotton delivered a gross farm income gain of about \$116.7 million in 2015. In the 1996–2015 period, the total gross farm income benefit was \$1.77 billion. As with other GM HT traits, these farm income gains have mainly arisen from cost savings (73% of the total gains), although there have been some yield gains in Argentina, Brazil, Mexico and Colombia (Table 3).

TABLE 3. GM HT cotton summary of average gross farm income impacts 1996–2015 (\$/hectare).

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Other HT Crops

GM HT canola (tolerant to glyphosate or glufosinate) has been grown in Canada, the US, and more recently Australia, while GM HT sugar beet is grown in the US and Canada. These crops have also benefited from the adoption of HT technology. The benefit has derived from the adoption of GM HT traits. Since 1996, it



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GM IR

The main benefit has been derived from the adoption of GM HT traits (Table 5).

TABLE 5. Average (%) yield gains GM IR cotton and maize 1996–2015.



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The greatest improvement in yields has occurred in developing countries, where conventional methods of pest control have been least effective (eg, reasons such as less well developed extension and advisory services, lack of access to finance to fund use of crop protection application equipment and products), with any cost savings associated with reduced insecticide use being mostly found in developed countries. These effects can be seen in the level of farm income gains that have arisen from the adoption of these technologies, as shown in Table 6.

TABLE 6. GM IR crops: Average gross farm income benefit 1996–2015 (\$/hectare).



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America (Argentina, Bolivia, Brazil, Colombia, Paraguay and Uruguay), mostly from GM technology in soybeans and maize. GM IR cotton has also been responsible for an additional \$38.2 billion additional income for cotton farmers in China and India.

In 2015, 48.7% of the farm income benefits were earned by farmers in developing countries. The vast majority of these gains have been from GM IR cotton and GM HT soybeans. Over the 20 y 1996–2015, the cumulative farm income gain derived by developing country farmers was \$86.1 billion, equal to 51.3% of the total farm income during this period.

The cost to farmers for accessing GM technology, across the 4 main crops, in 2015, was equal to 29% of the total value of technology gains. This is defined as the farm income gains referred to above plus the cost of the technology payable to the seed supply chain. Readers should note that the cost of the technology accrues to the seed supply chain including sellers of seed to farmers, seed multipliers, plant breeders, distributors and the GM technology providers.

In developing countries, the total cost was equal to 20% of total technology gains compared with 36% in developed countries. While circumstances vary between countries, the higher share of total technology gains accounted for by farm income in developing countries relative to developed countries reflects factors such as weaker

provision of public goods, higher seed prices, and higher seed multiplication rates in developing countries and

Seventy percent of the total farm income gains from GM technology in 2015 were from higher yields, mostly on insecticide and herbicide resistant crops. The total income gain relative to cost of technology was 16% in 2015. Thus in 2015 the total farm income gain was 16% and 16%

Crop P

Based on the data presented in the table above



have added important volumes to global production of corn, cotton, canola and soybeans since 1996 (Table 7).

TABLE 7. Additional crop production arising from positive yield effects of GM crops.



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The GM IR traits, used in maize and cotton, have accounted for 94.7% of the additional maize production and 98.9% of the additional cotton production. Positive yield impacts from the use of this technology have occurred in all user countries, except for GM IR cotton in Australia where the levels of *Heliothis* sp (boll and bud worm pests) pest control previously obtained with intensive insecticide use were very good. The main benefit and reason for adoption of this technology in Australia has arisen from significant cost savings and the associated environmental gains from reduced insecticide use, when compared with average yields derived from crops using conventional technology (such as application of insecticides and seed treatments). The average yield impact across the total area planted to these traits over the 20 y since 1996 has been +13.1% for maize and +15% for cotton.

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The use of crop biotechnology, by 18 million farmers in 2015, has delivered important farm income benefits over the 20-year period to 2015. The GM IR traits have mostly delivered higher incomes through improved yields in all countries. Many farmers, especially in developed countries, have also benefited from lower costs of production (less expenditure on insecticides). The GM HT technology-driven farm income gains have mostly arisen from reduced costs of production, notably on weed control. In South America, the technology has also facilitated the move away from conventional to low/no-tillage production systems and, by effectively shortening the production cycle for soybeans, enabled many farmers to plant a second crop of soybeans after wheat in the same season. In addition, second generation GM HT soybeans, now widely used in North America, are delivering higher yields, as are the new 'stacked' traited HT and IR soybeans being used in South America since 2013.

In relation to HT crops, over reliance on the use of glyphosate and the lack of crop and herbicide rotation by farmers, in some regions, has contributed to the development of weed resistance. To address this problem and maintain good levels of weed control, farmers have increasingly adopted more integrated weed management strategies incorporating a mix of herbicides, other HT crops and cultural weed control measures (in other words using other herbicides with glyphosate rather than solely relying on glyphosate, using HT crops which are tolerant to other herbicides, such as glufosinate

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The report is based on extensive analysis of existing farm level impact data for GM crops, much of which can be found in peer reviewed literature. Most of this literature broadly refers to itself as 'economic impact' literature and applies farm accounting or partial budget approaches to assess the impact of GM crop technology on revenue, key costs of production (notably cost of seed, weed control, pest control and use of labor) and gross farm income. While primary data for impacts of commercial cultivation were not available for every crop, in every year and for each country, a substantial body of representative research and analysis is available and this has been used as the basis for the analysis presented. In addition, the authors have undertaken their own analysis of the impact of some trait-crop combinations in some countries (notably GM herbicide tolerant (HT) traits in North and South America) based on herbicide usage and cost data.

As indicated in earlier papers, the 'economic' impact of this technology at the farm level varies widely, both between and within regions/countries. Therefore, the measurement of impact is considered on a case by case basis in terms of crop and trait combinations and is based on the average performance and impact recorded in different crops by the studies reviewed. Where more than one piece of relevant research (eg, on the impact of using a GM trait on the yield of a crop in one country in a particular year) has been identified, the findings used in this analysis reflect the

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weaknesses. To reduce the possibilities of over/understating impact due to these factors, the analysis:

- Directly applies impacts identified from the literature to the years that have been studied. As a result, the impacts used vary in many cases according to the findings of literature covering different years. Examples where such data are available include the impact of GM insect resistant (IR) cotton: in India (see Bennett et al. ([2004](#)); IMRB ([2006](#)) and IMRB ([2007](#))), in Mexico (see Traxler and Godoy-Avila ([2004](#)) and Monsanto Mexico annual monitoring reports submitted to the Ministry of Agriculture in Mexico) and in the US (see Sankala and Blumenthal ([2003](#), [2005](#)), Mullins and Hudson ([2004](#))). Hence, the analysis takes into account variation in the impact of the technology on yield according to its effectiveness in dealing with (annual) fluctuations in pest and weed infestation levels;
- Uses current farm level crop prices and bases any yield impacts on (adjusted - see below) current average yields. This introduces a degree of dynamic analysis that would, otherwise, be missing if constant prices and average yields identified in year-specific studies had been used;
- It includes some changes and updates to the impact assumptions identified in the literature based on new papers, annual consultation with local sources (analysts, industry and some 'own a
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be) available and used by farmers and there are studies that have assessed trait-specific impacts;

- All values presented are nominal for the year shown and the base currency used is the US dollar. All financial impacts in other currencies have been converted to US dollars at prevailing annual average exchange rates for each year (source: United States Department of Agriculture Economics Research Service);
- The analysis focuses on changes in farm income in each year arising from impact of GM technology on yields, key costs of production (notably seed cost and crop protection expenditure but also impact on costs such as fuel and labor. Inclusion of these costs is, however, more limited than the impacts on seed and crop protection costs because only a few of the papers reviewed have included consideration of such costs in their analysis. In most cases the analysis relates to impact of crop protection and seed cost only, crop quality (eg, improvements in quality arising from less pest damage or lower levels of weed impurities which result in price premia being obtained from buyers) and the scope for facilitating the planting of a second crop in a season (eg, second crop soybeans in Argentina following wheat that would, in the absence of the GM HT seed, probably not have been planted). Thus, the farm income effect measured is essentially a gross margin impact (impact on gross revenue less variable costs of production) rather than a full net cost of production. The analysis does not take into account the impact of world prices.

The paper examines the impact of GM technology at the crop level from the perspective of the farmer. The impact is measured from the yield and farm income in relation to the year 2000 (or 2015) are shown in Figure 1.



DISCL

FUNDING

The authors acknowledge that funding toward the researching of this article was provided by Monsanto. The material presented in this paper is, however, the independent views of the authors – it is a standard condition for all work undertaken by PG Economics that all reports are independently and objectively compiled without influence from funding sponsors.

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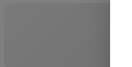
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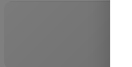
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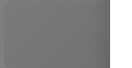
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Appendix 1. Details of the calculation of the 2015 farm income calculation

GM IR

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GM IR cotton 2015

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GM HT soybeans 2015 (excluding second crop soybeans - see separate table)

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GM IR

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GM HT

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GM HT cotton 2015

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GM HT canola 2015

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Second soybean crop benefits: Argentina

An additional farm income benefit that many Argentine soybean growers have derived comes from the additional scope for second cropping of soybeans. This has arisen because of the simplicity, ease and weed management flexibility provided by the (GM) technology which has been an important factor facilitating the use of no and reduced tillage production systems. In turn the adoption of low/no tillage production systems has reduced the time required for harvesting and drilling subsequent crops and hence has enabled many Argentine farmers to cultivate 2 crops (wheat followed by soybeans) in one season. As such, the proportion of soybean production in Argentina using no or low tillage methods has increased from 34% in 1996 to 90% by 2005 and has remained at over 90% since then.

Farm level income impact of using GM HT soybeans in Argentina 1996–2015 (2): Second crop soybeans

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Example: GM IR cotton (2015)

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Appendix 2: Impacts, assumptions, rationale and sources for all trait/country combinations

IR corn (resistant to corn boring pests)

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Readers should note that the assumptions are drawn from the references cited supplemented and updated by industry sources (where the authors have not been able to identify the sources). The authors have not been able to identify the sources of the herbicide resistance trait. According to the authors, the information provided in this table is based on the information provided by the authors. The authors are confident that the information provided in this table is accurate. The authors suggest that the information provided in this table should be used as a guide only. The authors have not been able to identify the sources of the information provided in this table.



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